SOLIDIFICATION PHENOMENA AND PROPERTIES OF SOME CAST TOOL STEELS

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Abstract The freezing process, microstructures and phase relationships in some experimental cast tool steels have been investigated and developed under the various solidification conditions. Experimental steels were based on AISI M2 and M10 grades high speed steels. Addition of carbide forming elements such as niobium and titanium with and without extra carbon were made to the molten bath of the base steels. The chemical composition adjustment and the microstructural and property changes are discussed in relation of possibilities for the development of tools cast close to finished shape with acceptable mechanical properties and lower production cost.

چکیده: جهت بررسی و توسعه خواص فولادهای ابزار ریختگی فرآیند انجماد و ریزساختار بعضی از این فولادها تحت شرائط مختلف انجماد مورد ارزیابی قرار گرفت. نمونه های آزمایشی از فولادهای تند برنوع M 2 و M 10 انتخاب و ضمن افزودن عناصر کاربیدزای قوی به مذاب این فولادها فازهای ایجاد شده در ساختار آنها تحت شرائط مختلف انجماد شناسائی و بررسیهای لازم در خصوص ارتباط بین ترکیب شیمیایی، ریزساختار و خواص نمونه های آزمایشی در راستای بهینه سازی خواص این فولادها انجام گردید.

INTRODUCTION

Tool steels are characterized by their high hardness and wear resistance coupled in many instances with resistance to softening at the elevated temperatures produced by high speed machining. Since the beginning of this century, due to their commercial and economical importance, tool steels have been widely investigated and many books and articles published on the various aspects of their constitution and properties including for example solidification process [1, 2], the influence of carbon and alloy content [3-5], and mechanical properties [6, 7].

The properties required from the tooling are quite diversified and depend on the conditions under which the tool is to be used such as the nature of the forces applied, the temperatures encountered and other additional factors like lubrication.

smart[8] has mentioned that the tool requirements differ for tool producers and tool users. Adequate strength and strength retention at temperature, resistance to thermal shock and wear, toughness and finally chemical stability are the producer's summary of requirements, while the user will tend to state his requirements in terms of function rather than property. User requirements might be listed as: adequate tool life, avoidance of premature tool failure, reproducibility in cutting performance, applicability to a variety of machining operations and finally ability to be brazed. The required properties in the tool itself depend on the particular forming process. In some cases high temperatures are encountered, with or without impact so hardness at elevated temperatures is essential, while in other cases a high degree of wear resistance at lower temperatures is the primary requirement.

It is generally believed that of the many physical and mechanical properties of tool steels, hardness, toughness and wear resistance have more effect on tool performance. The properties required for the particular application of tool steels are developed by combinations of mechanical deformation and heat treatment to the selected alloy steels. These combinations result in resistance to deformation and softening at elevated temperatures and loads, high wear resistance and adequate toughness. All of which are major requirements in tool application.

The properties of tool steels depend on microstructure. The idealized microstructure of a tool steel is generally considered to consist of a tough (fine grained tempered martensitic) matrix, containing a sub- microscopic dispersion of secondary hardening carbides and discrete primary and eutectic carbides of spherical shape with homogeneous distribution and small size. This type of microstructure might be obtained either by powder metallurgy technique or by conventional methods: ingot casting and hot mechanical deformation. Tool manufacture through the latter route usually involves high cost toolroom operation for generating the shape of the tools.

Cast structures of tool steels in general and especially in the case of large bar sizes are relatively course, with marked dendritic features, and massive carbide networks, thus the influences of carbide segregation and structure modifiers on the mechanical properties of tool steels are worthy of investigation. Melting practice and carbide distribution have also effects on mechanical properties. The size and morphology of either the primary or the secondary carbides are the important factors in determining the properties of tool steels.

Modification of the cast structure of M2 and M10 high speed steel by introducing the strong carbide forming elements into the melt together with extra carbon in stoichiometric proportion has been described in an earlier paper [9]. In the present work solidification phenomena, formation of various carbides and the influence of strong carbide forming elements on the properties of experimental steels together with chemical composition adjustment have been investigated.

EXPERIMENTAL PROCEDURES

Three groups of alloy of the composition shown in Table 1 were investigated; (a) M2 and M10 high speed steels with conventional chemical composition; (b) alloys of type M2 and M10 with niobium, titanium and carbon contents were investigated to study the influence of strong carbide forming elements on the microstructure and properties of cast conventional high speed tool steels. (c) steels; with amended composition based on (a) and (b) groups were investigated to study the methods of adjusting chemical composition for producing new tool steels with modified structure, higher performance and lower cost.

The steels were produced by air melting in a high frequency induction furnace and the castings were made by investment casting method to produce sets of cast bars 100 mm in length and in diameters from 2-24 mm as shown in Figure 1.

Transverse specimens were cut from the cast bars. These were mounted in Bakelite and mechanically

Table 1. Composition (wt %) of experimental cast steels (main elements)

Steel	C	Mo	Cr	W	V	Nb	Ti	Fe+traces
M2	0.9	5.57	4.30	6.57	2.10	-	-	bal
M10	0.91	8.00	4.30	-	2.10	-	-	bal
M2+NbC	1.47	5.57	4.16	6.75	2.26	4.36	-	bal
M10+NbC	1.47	8.00	4.16	-	2.26	4.36	-	bal
M2+TiC	1.33	5.57	4.16	6.75	2.26	-	3.91	bal
M10+TiC	1.33	8.00	4.16	-	2.26	-	3.91	bal
M1245	1.41	5.00	4.16	2.60	1.12	4.27	-	bal

Table 2. Hardness, impact and wear test results

Steel	Hardness (HV50)	Charpy impact value (J)	Weight loss (mg/8hr)
M2	591	27.2	82
M10	453	27.8	89
M2+Nb(C)	671	6.8	39
M10+Nb(C)	658	7.2	41
M1245	750	10.9	38

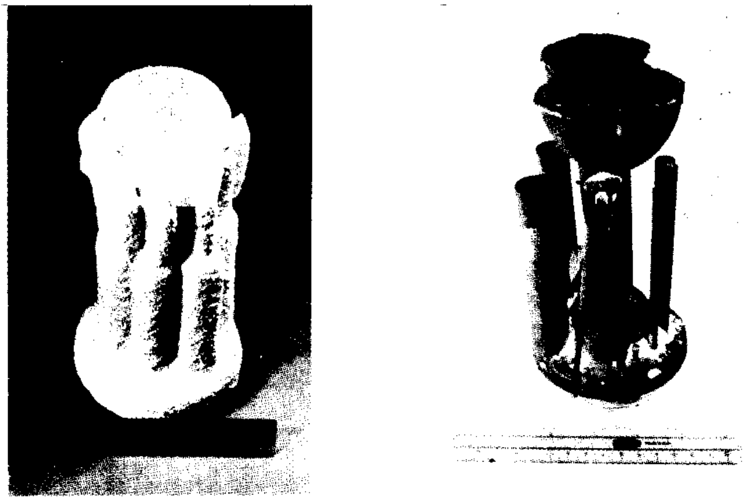

Figure 1. Casting method employed for investment cast tool steel bars. (a) mould (b) casting

polished to 1 micron meter. The specimens were first etched in 5% nital solution for 1 minute and then in Oberhoffers reagent for 5 seconds. at this stage they were ready for light optical microscopy examination then they were deeply etched for 1-2 minutes in the deep etch solution. This solution was a mixture of Conc. HCl 5 ml, 4% picral 45 ml, 5% Nital 50 ml. It overetched the matrix and left the carbide particles standing slightly proud of the surface.

Scanning electron microscopy was carried out to study the morphology and distribution of the carbides observed in the microstructures. The specimens were subsequently subjected to further examination on the energy dispersive X-ray analysis (EDX) for identification of the carbides. Some relevant mechanical properties of the steels were also investigated using hardness, impact and cutting performance testing.

The experimental observation using above mentioned techniques will now be reported with representetive micrographs and other obtained data.

RESULTS AND DISCUSSION

The influence of the niobium and titanium as the strong carbide forming elements on the cast structures has been described in an earlier paper [9]. It has been found that the NbC and TiC particles exert an inoculating effect and modify the cast course dendritic structure to produce fine grains. Figure 2 summarized this general influence on the microstructure of high speed tool steels.

The formation of dendrites is the most basic characteristic of the solidification process for the M2 and M10 high speed steels. The dendritic structures of these steels are illustrated in Figures 3 and 4. According to these micrographs the fishbone and rod-shaped carbide types seem to be dominant in the M2 and M10 high speed steels. These segregate in the interdendritic regions and freeze in the last stages of solidification by eutectic reaction. so they can also be referred to as eutectic carbides.

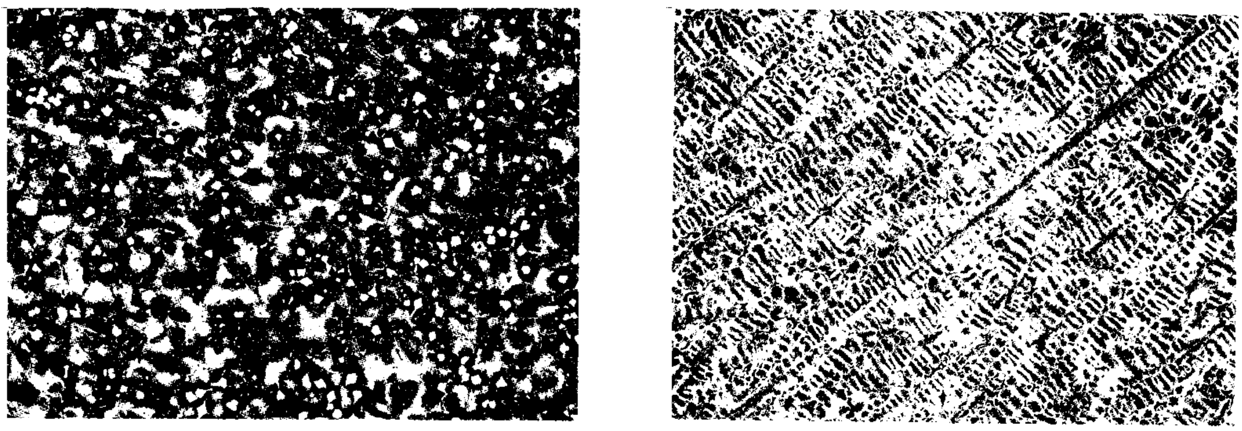

Figure 2. Cast structure of (a) normal M2HSS, (b) modified M2HSS

Figure 3. Cast structure of M2 HSS

Figure 4. Cast structure of M10 HSS

The eutectic carbides presented in M2 and M10 HSS are complex in nature. Micrograph presented in Figure 5 is part of the fishbone eutectic carbide observed in the M2 cast structure at high magnification. The actual analysis relating to the carbides is also presented in this figure as a typical map distribution of the elements W, Mo and Fe. As can be seen, the concentrations of W and Mo are higher in the main body of the carbide and the Fe distribution is highest in the matrix structure. Two typical structures developed with the addition of Nb and Ti together with extra carbon to the molten bath leading to the formation of NbC and Tic are shown in Figures 6 and 7. As can be seen from these Figures not only primary NbC and TiC carbides have been formed but also the coarse cast structure has been modified to a relatively fine equiaxed type. These primary carbides particles were identified by X-ray analysis on the scanning electron microscope. Table 2 shows some of the mechanical properties of the experimental steels. As can be seen from this table, the hardness and wear resistance were increased by the introduction of the NbC and TiC into the base material but toughness was decreased. In order to improve the available combination of hardness and toughness further experiments were undertaken to adapt the base composition to obtain increased matrix toughness. The matrix composition of M2 after hardning at 1200°C was reported by Steven at al.[10] to be 2%W, 2.8% Mo, 1.3% V, 4.4%Cr, 0.49% C and 88.4% Fe. Roberts [11] also reported almost the same composition. According to their results it couldbe assumed that the remaining contents of the above mentioned alloying elements are present in undissloved eutectic carbides. These carbides, which are usually in the form of M_6C and M_2C, could be replaced by primary niobium and titanium carbides, which undoubtedly promote hardness and wear resistance.

In the present research programme the chemical composition adjustment was selected on the above reasoning, so the amounts of W, Mo and V were reduced in the M2+Nb (C) and M10+Nb (C) steels. One of the amended steels was designated as M1245 and the results obtained from this steel will now be summarized.

The amended composition was as shown in Table 1. Figure 8 shows the microstructure for this steel in the as-cast condition, two different NbC morphologies were observed. In the thin section (Figure 8a) the niobium carbide appeared in a dendritic shape which was quite different from the compact idiomorphic morphology observed in thicker sections(Figure 8b). The dendritic morphology appears to result from the particular combination of cooling rate and composition of the steel.

As a result of the change in composition, the mechanical properties of the steel were found to have been improved (Table 2). There is seen to be a significant increase in the hardness of M1245 steel as compared with both the base M2 and the M2+Nb (C) containing almost the same amount of primary niobium carbide. The reason for the increasing hardness could be the distribution of the small niobium carbide particles throughout the matrix. The change of composition also produced an increase in toughness. This was undoubtedly due to the observed reduction in the amounts of the intergranular rod-shaped carbides normally precipitated late in the freezing process.

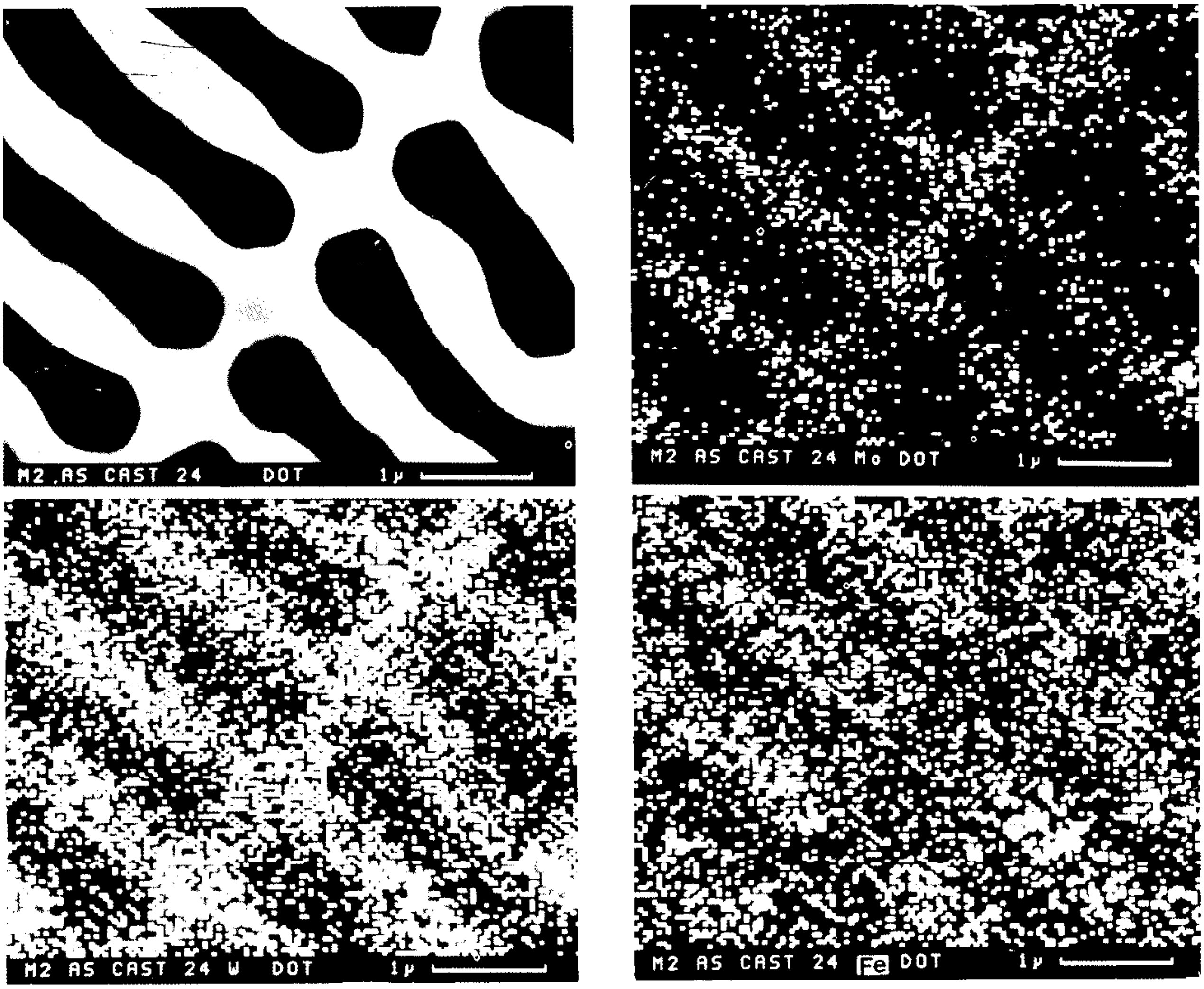

Figure 5. Distribution of W, Mo and Fe in eutectic region of cast M2 HSS.

Figure 8b clearly demonstrates the reduced content of eutectic carbides.

It can be deduced as a whole that adjustment in composition and structural modifications to steels of the high speed type can greatly enhance their properties in the cast state. Not only can wear resistance be increased by the introduction of the NbC and TiC but favourable changes in microstructure, as compared with the cast structures associated with conventional compositions, should enable better toughness to be obtained than that normally expected in cast tool materials.

CONCLUSION

Stoichiometric additions of Nb+C or Ti+C to molten bath of M2 and M10 high speed steels result in the formation of primary NbC or TiC particles in the liquid. These particles modify the coarse dendritic cast structure and offer potential for the development of cast high speed steel tooling. Hardness and wear resistance increase with the introduction of primary NbC and TiC into the cast structures, but impact properties are reduced. Adjustments of the composition with a view to the reduction of the coarse eutectic carbides networks cannot only restore toughness but also contribute to still higher hardness.

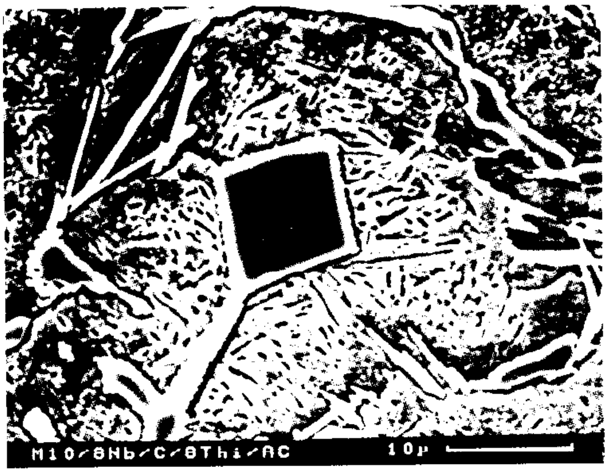

Figure 6. Cast structure of M10+NbC

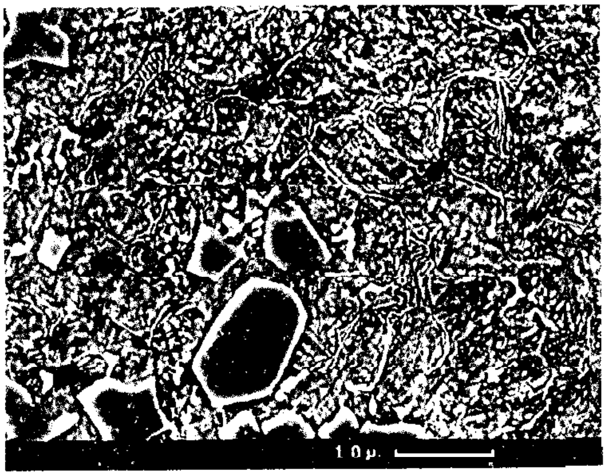

Figure 7. Cast structure of M10+TiC

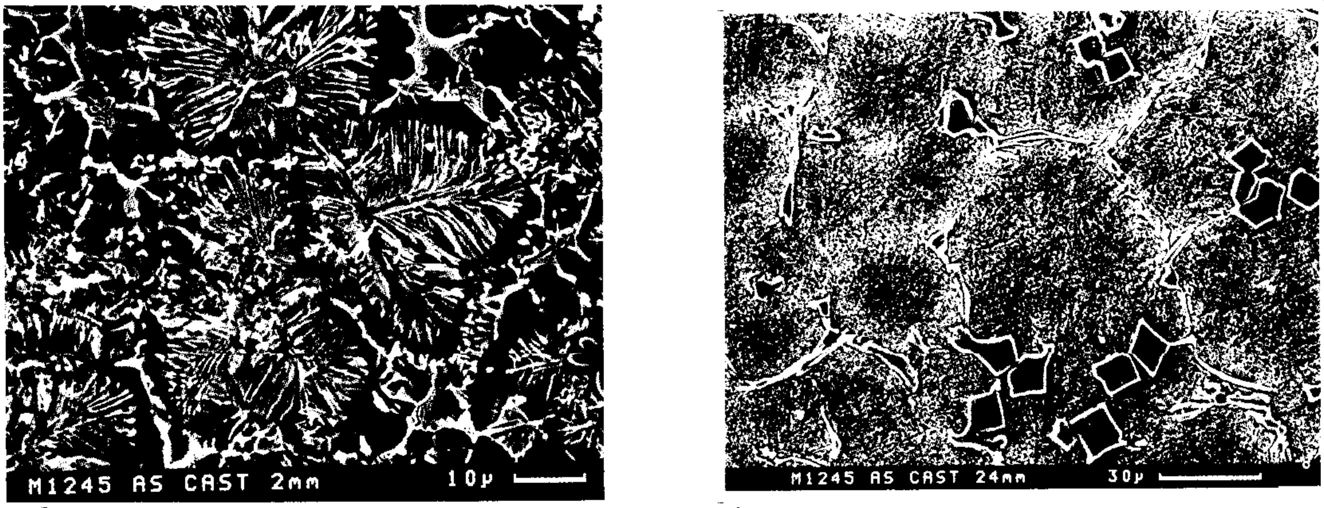

Figure 8. Cast structure of M1245 steel. (a) 2 mm dia. bar.

(b) 24 mm dia. bar.

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